

UNCERTAINTY ESTIMATION IN ELECTROMAGNETIC FIELD MEASUREMENTS FOR ASSESSING COMPLIANCE WITH SAFETY LIMITS

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ABSTRACT

The Greek Atomic Energy Commission (EEAE) carries out measurements in the vicinity of all kinds of facilities emitting RF electromagnetic fields, in order to monitor whether the general public exposure limits are being adhered to. The estimation of uncertainty in these measurements is imposed by accreditation (EEAE is accredited according to EN ISO/IEC 17025 standard for performing this kind of measurements) and is crucial in the cases where measured values are close to the safety limits. The uncertainty sources in the case of electromagnetic field measurements with isotropic and broadband probes (absolute error, frequency response, linearity, isotropic deviation, thermal response and modulation) are explained and the procedure followed by EEAE for their estimation is presented. Some practical aspects are presented, along with the estimations of the uncertainties related to each source as well as the expanded uncertainty.

1 INTRODUCTION

International competent bodies such as IEEE, [1], [2], and the International Commission on Non-Ionizing Radiation Protection (ICNIRP), [3], have issued limit values for the protection of people from electric, magnetic and electromagnetic fields. The Council of the European Union issued in 1999 a Recommendation, [4], adopting ICNIRP's limit values for the protection of the general public. Implementing this Recommendation, Greece has put into force two new national legislative acts concerning the protection of the public from exposure to low frequency electric and magnetic fields, [5], and from exposure to electromagnetic fields emitted by all kinds of land-based antenna stations, [6]. Regarding the electromagnetic fields emitted by antenna stations, the safety limits in Greek legislation were set to 80% of the European Recommendation reference values while in the case of extremely low frequency fields, the limit values are the same as in the Recommendation.

The competent national authority for the protection of the general public and the environment against artificially produced non-ionizing radiation in Greece is the Greek Atomic Energy Commission (EEAE), which lies under the Ministry of Development. To this end, the EEAE carries out measurements in the vicinity of all kinds of facilities emitting radio frequency electromagnetic fields (e.g. audio, radio and television antennas, mobile phone base stations, radar & satellite earth stations and other microwave communication systems), in order to monitor whether the general public exposure limits are being adhered to. In January of 2003, the Non Ionizing Radiation Office of the EEAE was accredited in accordance with the requirements of the EN ISO/IEC 17025 standard by the Hellenic Accreditation Council (ESYD - the Greek National Accreditation Body) for performing this kind of measurements.

This accreditation imposes a detailed analysis concerning the measurement uncertainty (type A and type B evaluation). Furthermore, in the case where a measured value is lower than, but close to the safety limit, the measurement uncertainty must be estimated as accurately as possible in order to ensure that the exposure is indeed lower than the limit. This is a very crucial procedure, since according to the national legislation [5], [6], in case of excess of the safety limits, the operation of an installation shall be prohibited and administrative and technical measures have to be taken.

Many of the factors influencing the uncertainty are described in [7]. These factors are also briefly described in the next paragraphs. In order to estimate the magnitude of the partial uncertainties the instrument's manufacturer usually provides valuable information about the typical values for them. Also, there are specialized laboratories providing calibration facilities traceable to national standards. EEAE uses the information provided by the instrument manufacturer and a laboratory accredited with EN ISO/IEC 17025 for calibrating the instruments at an extensive set of field values and frequencies (calibration points). This set of points was chosen by EEAE and is focused on field values that are close to ICNIRP's reference levels for general public exposure and frequencies usually found as those utilized by radio FM band, TV-UHF stations, the GSM 900, GSM 1800 and UMTS mobile phone base stations, etc.

2 PARTIAL UNCERTAINTY SOURCES AND ESTIMATION

The uncertainty sources in the case of electromagnetic field measurements with isotropic and broadband probes are: absolute error, frequency response, linearity, isotropic deviation, thermal response and modulation. In the following paragraphs these terms are briefly explained and the procedure followed by EEAE for their estimation is presented.

The absolute error (Δ_{abs}) is virtually inevitable and includes the calibration method errors attributed to the instruments used by the calibration laboratory and to the calibration procedure. The value for this uncertainty is set equal to the calibration uncertainty. In order to be sure that the deviation from this value is small we recalibrate our instruments before the completion of two years so that any long-term drift of the instrument response is minimized.

The uncertainty due to the frequency response (Δ_{freq}) is the change of the instrument response at different frequencies of the measured field. If the frequency of the measured field is known, the frequency response error can be minimized with the use of correction factors. In order to cover the most realistic cases, we have ordered the calibration of our instruments at the most usually encountered frequencies as those utilized by radio FM band, TV-UHF stations, the GSM 900, GSM 1800 and UMTS mobile phone base stations etc. Typical values of this error vary from 0,5 dB to 3 dB. Figure 1 shows the frequency response of an electric field probe type 18 manufactured by Wandel & Goltermann and possessed by EEAE. This probe is specified for use in the frequency range from 100 kHz to 3 GHz.

The uncertainty due to linearity is (Δ_{lin}) is defined as the change of the instrument's accuracy at different values of the measured field. This uncertainty is general much lower in the middle of the instrument's dynamic range than at the ends of it. Because our ultimate purpose is to compare the measured values with safety limits we insist on the calibration of our instruments at field values close to 80% of ICNIRP's reference values (the safety limits in set in the Greek Legislation). Also, for one frequency the instruments are calibrated at many field levels. Figure 2 shows the linearity calibration of an electric field probe type 18 manufactured by Wandel & Goltermann and possessed by EEAE. This probe's measurement range is from 0.2 to 320V/m.

The uncertainty due to isotropic deviation (Δ_{isotr}) is the change of the instrument response when the instrument's direction changes. During its calibration, the instrument is rotated inside the field and the maximum and minimum displayed values are recorded. This allows the estimation of an uncertainty attributed to anisotropy. For example for the above-mentioned probe this uncertainty is 1.2dB.

The thermal response error (Δ_{env}) is the uncertainty that comes from the operation of the instrument in extreme environmental conditions (temperature, humidity, etc). Usually, this uncertainty occurs during the coldest winter days due to the very low temperatures. The manufacturer of the above-mentioned instrument defines the temperature range from 0 to +50° C. The typical uncertainty specified by the manufacturer in this range is from +0.2dB to -1.5dB, [10].

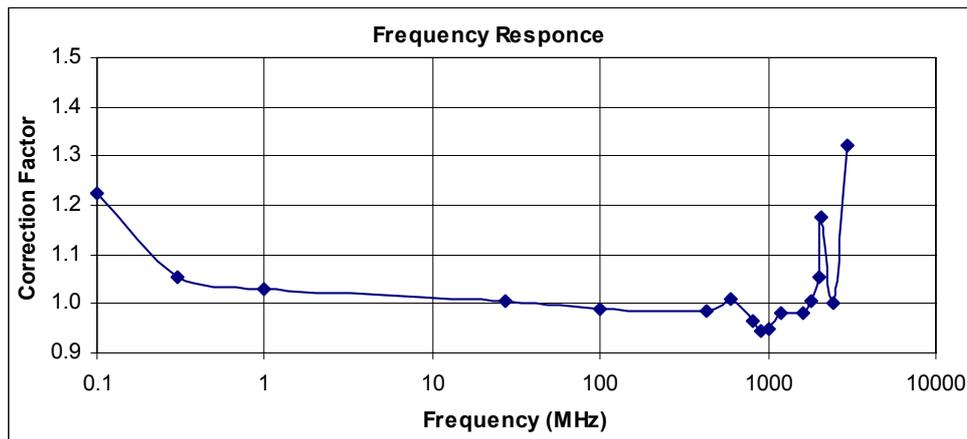


Fig 1. Frequency response of a Wandel & Goltermann electric field probe type 18, [9]. The applied electric field level was 27.5 V/m.

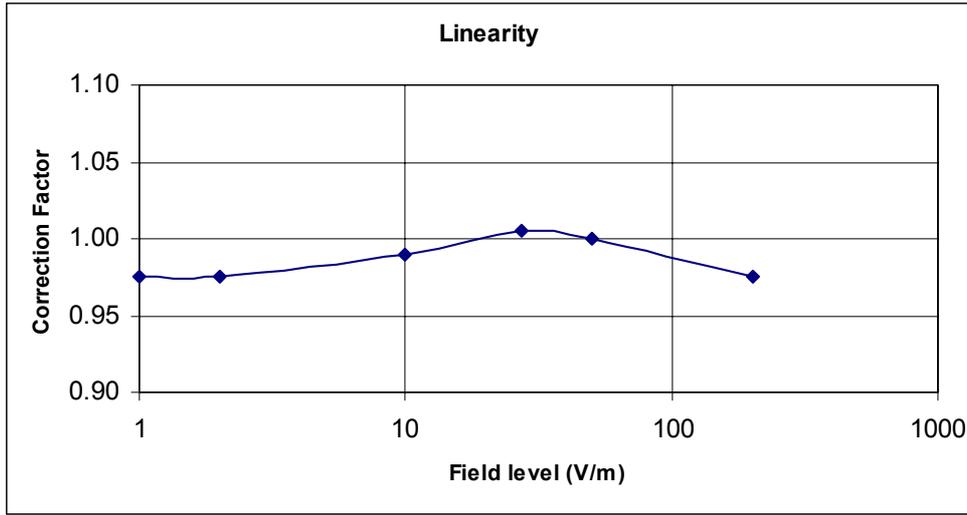


Fig 2. Linearity of a Wandel & Goltermann electric field probe type 18, [9]. The applied field frequency was 27.12 MHz.

The uncertainty due to modulation is (Δ_{mod}) is the effect of the measured field modulation on the instrument response. Generally, the modulation uncertainty appears in cases where there is AM and the field intensity is greater than 20V/m. The effect of amplitude modulation is attributed to the loss or quadratic response of the diodes used for the signal rectification and rms calculation. Also, relevant to this uncertainty is the error in measurements of multifrequency fields. In [8] the uncertainty due to multifrequency fields and modulation is further explained. The FM radio signals do not suffer significant errors due to their modulation. The measured values of TV-AM signals may need a correction factor between 0.58 and 1.19 in the worst case. Similarly, GSM signals may need a correction factor between 0.60 and 1.57 in the worst case.

The measurements of radar signals exhibit increased difficulties because of the signal pulsed modulation. The extreme crest factor makes once again the diode based probes to function in their linear area. There are no such problems with the use of thermocouple probes, which always have a true rms response. However, these probes have a smaller dynamic range and can be more easily destroyed due to overheat in comparison with diode probes.

3 TOTAL UNCERTAINTY ESTIMATION

The partial uncertainty sources applying in the case of high frequency (100kHz – 3GHz) electromagnetic field measurements with isotropic and broadband probes are shown in Table 2 along with some typical values for them. In practice the use of correction factors can reduce the uncertainty. Also, for purposes of comparison with safety limits it is common practice to err on the safe side and consider correction factors that overestimate the field levels when uncertainty exists. On a similar sense, when there are many frequencies present it is common practice to compare with the minimum reference level corresponding to these frequencies (when there is not a shaped frequency probe). That's because it is not possible to demonstrate through emf measurements an excess of a safety standards basic restriction (such as SAR); it is only possible to demonstrate that the measured values are below the reference levels and so the values comply with the standard. If the reference levels are exceeded it is not necessary that the basic restrictions are also exceeded.

After the estimation of the contribution of each one relative uncertainty, the combined uncertainty δU is calculated in accordance with (1).

$$\delta U = \sqrt{\sum u_i^2} = \sqrt{\frac{1}{3}(\Delta_{abs}^2 + \Delta_{freq}^2 + \Delta_{isotr}^2 + \Delta_{lin}^2 + \Delta_{env}^2 + \dots)} \quad (1)$$

Assuming a confidence interval of 95% ($k = 2$) the expanded uncertainty is $U_e \cong 2\delta U$, or if the standard deviation of the measurements σ is taken into account, it is given in (2).

$$U_e = 2\sqrt{\sum u_i^2 + \sigma^2} \quad (2)$$

The expanded uncertainty usually never exceeds 3db.

In order to declare that an measured exposure level complies with the safety limits imposed in the Greek Legislation, EEAE demands the measured values plus the expanded uncertainty to be below the reference values. Otherwise, EEAE cannot guarantee that the exposure measurements comply with the safety limits.

Table 2. Assessment of the uncertainty sources usually encountered when measuring rf electromagnetic fields.

Uncertainty Source	Estimation Technique	Probability Distribution	Divisor	Sensitivity Coefficient	Typical value	Actual Value Δ_i (%)
absolute error (it includes calibration accuracy error)	1	Rectangular	$3^{1/2}$	1	± 1 dB	Δ_{abs}
frequency response error	1	Rectangular	$3^{1/2}$	1	± 1 dB	Δ_{freq}
linearity error	1	Rectangular	$3^{1/2}$	1	± 1 dB	Δ_{lin}
isotropic deviation error	1	Rectangular	$3^{1/2}$	1	± 1 dB	Δ_{isotr}
thermal response error	2	Rectangular	$3^{1/2}$	1	± 1 dB	Δ_{env}
GSM Modulation error	2	Rectangular	$3^{1/2}$	1	< 10%	Δ_{GSM}
Pulsed field modulation (radars)	2	Rectangular	$3^{1/2}$	1	± 2 dB	Δ_{PM}

1 Estimation through the calibration procedure

2 Estimation through the manufacturer data sheet

4 REFERENCES

- [1] IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Std C95.1-1991 (1999 Edition), The Institute of Electrical and Electronics Engineers, New York, 1999.
- [2] IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields 0 to 3 kHz, IEEE Std C95.6-2002
- [3] International Commission on Non-Ionizing Radiation Protection: Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields. Health Physics 74:494-522, 1998.
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- [7] IEEE std C95.3-2002. IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields (100kHz – 300GHz).
- [8] H. Keller, Wandel & Goltermann Research Report No3, Standardized Personal Safety Measurements in the RF and Microwave Range with the EMR-20 / EMR-30 field strength meter (available on-line: http://www.narda-sts.de/pdf/fachartikel/3_standardized_personal.pdf).
- [9] National Physical Laboratory, Certificate of Calibration No E0207171/5, December 2002.
- [10] Narda Safety Test Solutions, E-Field Probe Type 18 datasheet (available on-line: http://www.narda-sts.de/pdf/datenblatt/e_sond18.pdf).